Pergamon

J. stored Prod. Res. Vol. 30, No. 1, pp. 87–94, 1994
Elsevier Science Ltd
Printed in Great Britain
0022-474X/94 $6.00 + 0.00

# Efficacy of Unsynergised Deltamethrin and Deltamethrin + Chlorpyrifos-methyl Combinations as Protectants of Stored Wheat and Stored Corn (Maize)*

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*(Received 11 November 1992; in revised form 11 June 1993)*

**Abstract—Soft red winter wheat and "Pioneer 3320" corn (maize) were treated with either 0.5, 0.75, 1.0 ppm deltamethrin, 0.5 ppm deltamethrin + 6.0 ppm chlorpyrifos-methyl, 1.0 ppm deltamethrin + 6.0 ppm chlorpyrifos-methyl, or 6.0 ppm chlorpyrifos-methyl, and subsequently stored for 10 months. Bioassays were conducted every 2 months during this storage period. *Rhyzopertha dominica* (F.) and *Sitophilus oryzae* (L.) did not survive on the combination treatments applied to wheat. Survival of *R. dominica* in the three deltamethrin treatments was variable throughout the storage period but no $F_1$ adults were detected. *S. oryzae* survival on wheat treated with 0.5 ppm deltamethrin ranged from 0 to 84.5%. Maximum survival in the 0.75 and 1.0 ppm deltamethrin treatments was 26.2 and 3.5%, respectively. *Sitophilus zeamais* (Motsch.) or *Tribolium castaneum* (Herbst) did not survive in the combination treatments applied to corn. Maximum *S. zeamais* and *R. castaneum* survival in the three deltamethrin treatments was 23.5 and 18.7%, respectively, but there were no significant trends during storage and $F_1$ production was minimal.**

*Key words*—Grain, storage, protectants, pyrethroids, beetles.

## INTRODUCTION

The future status of malathion and pirimiphos-methyl, two organophosphorus insecticides registered in the United States, is questionable because of re-registration procedures required by the Environmental Protection Agency. Malathion is registered as a protectant of stored grains, and most if not all labels will soon be withdrawn (Abramson, 1991). Pirimiphos-methyl is registered as a protectant for corn (maize) and sorghum, and these labels may also be amended. Chlorpyrifos-methyl is registered for barley, oats, rice sorghum, and wheat. However, some populations of *Rhyzopertha dominica* (F.) are developing resistance to this insecticide (Zettler and Cuperus, 1990), and this species has been deleted from the label. New registered protectants would certainly be an asset to pest management programs for stored grain.

Several pyrethroids applied in combination with piperonyl butoxide synergist have been evaluated as protectants of wheat stored in Australia (Bengston *et al.*, 1980a, b; Bengston *et al.*, 1983; Bengston *et al.*, 1987). The application rates are usually lower than those used for comparable

*This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or a recommendation for its use by the USDA.

organophosphates, and unlike organophosphates, pyrethroid degradation rates do not generally increase as commodity temperature and moisture content increase. However, if a synergist is required to achieve protection at low application rates, the resulting increase in cost may limit the use of pyrethroids in the United States.

The pyrethroid deltamethrin is among those tested as a protectant for wheat stored in Australia. Samson and Parker (1989) exposed several field strains of *R. dominica*, *Sitophilus oryzae* (L.), and *Sitophilus zeamais* (Motsch.) on corn treated with unsynergised deltamethrin, and found that the *Sitophilus* species were not controlled by application rates that were effective against *R. dominica.* A subsequent trial with piperonyl butoxide synergist improved the efficacy of deltamethrin (Samson and Parker, 1990). Residues from deltamethrin applications degrade slowly on grain (Noble *et al.*, 1982) and the rates necessary for grain protection in the U.S. should be lower than the rates of the organophosphates currently registered for this purpose. The objective of this study was to determine the residual efficacy of unsynergised deltamethrin applied alone or in combination with chlorpyrifos-methyl to wheat and corn.

## MATERIALS AND METHODS

### *Insecticide treatments*

Soft red winter wheat and "Pioneer 3320" corn were obtained from a local granary, fumigated with phosphine, and stored at 4.4°C until the experiment was initiated. The commodities were removed from storage and allowed to warm for several days prior to treatment. Six insecticide treatments and an untreated control were evaluated and are listed as follows: untreated controls, 6.0 ppm chlorpyrifos-methyl, 0.5, 0.75, and 1.0 ppm deltamethrin, and 6.0 ppm chlorpyrifos-methyl combined with either 0.5 or 1.0 ppm deltamethrin.

Insecticide spray solutions were formulated from a 4 EC (1.82 kg/3.785 liter) chlorpyrifos-methyl source and a 0.5 EC (0.227 kg/liter) deltamethrin source (Gustafson, Inc, Plano, Texas). Each insecticide treatment was applied to wheat at the rate of 18.9 ml of formulated spray for 27.27 kg (1 bushel); each treatment was applied to corn at the rate of 18.9 ml of formulated spray per 25.45 kg (1 bushel). Untreated controls were sprayed at the same rate with distilled water. Each treatment was replicated four times on both commodities, and applications were made indoors using an insecticide delivery system equipped with a number 650033 Teejet nozzle (Spraying Systems, Wheaton, Illinois). After each replicate sample was treated, it was placed in a 0.31 $m^3$ cardboard box lined with a plastic bag, and these boxes were stored from 26 September 1990 to 7 August 1991 in an insulated metal shed with no environmental controls.

### *Wheat bioassays*

Immediately after treatment and after 2, 4, 6, 8 and 10 months of storage (11 November, 29 January, 27 March, 23 May and 7 August, respectively), approx. 320 g wheat from each replicate box was removed and placed in each of two 0.95 l jars. The jars were put in a laboratory control room (28 $\pm$ 1°C, 60 $\pm$ 2% r.h.), and 100 1–2 wk old *S. oryzae* were introduced into the first jar and 100 1–2 wk old *R. dominica* were introduced into the second jar. These species were obtained from pesticide-susceptible colonies maintained at the laboratory and reared under constant conditions (28 $\pm$ 1°C, 60 $\pm$ 2% r.h., 12:12 [L:D]). After 5 days the wheat was sifted, the number of live individuals of each species was recorded for each replicate, all live and dead insects were removed and discarded, and the jars were returned to the control room. After 49 days the wheat was resifted, $F_1$s were counted and the ground flour (dockage) was weighed.

### *Corn bioassays*

The sampling and bioassay processes are similar to those described for wheat, except that 1–2 wk old adult *S. zeamais* and 1–2 wk old red flour beetle *Tribolium castaneum* (Herbst) were used as the test species and 50 *S. zeamais* instead of 100 were introduced into a replicate jar. Also, when $F_1$ counts were made for *T. castaneum*, immatures and adults were recorded separately.

*Analysis*

The General Linear Model (GLM) Procedure of the Statistical Analysis System (SAS Institute, 1987) was used to determine means ± SEM at each sample interval. Where appropriate, regression equations were fitted for survival using the Regression Procedure (REG) to determine the significance of linear vs quadratic regression, and to fit the equations to the data. The Correlation procedure of SAS was used to correlate survival in all treatments with subsequent $F_1$ adults and dockage.

## RESULTS

*Wheat*

*R. dominica* survival on untreated wheat averaged 91.5 ± 1.6, 88.6 ± 1.7, 91.5 ± 1.2, 92.0 ± 3.3, 88.8 ± 2.1, and 94.0 ± 2.1% at months 0, 2, 4, 6, 8, and 10, respectively. *R. dominica* did not survive on wheat treated with either 0.5 ppm deltamethrin + 6 ppm chlorpyrifos-methyl or 1.0 ppm deltamethrin + 6.0 ppm chlorpyrifos-methyl. Survival on wheat treated with 0.5 ppm deltamethrin ranged from 17.0 to 48.2% during the test, and quadratic regression for increased survival with storage time was significant with an $R^2$ of 0.50 (Fig. 1A). Survival in the 0.75 ppm deltamethrin treatment ranged from 14.7 to 33.5% and increased slightly during the latter months of the test; the quadratic regression also fits the data for this treatment (Fig. 1B). Maximum survival in the 1.0 ppm-deltamethrin treatment was 14.0% at month 4, and even though a quadratic regression was fitted to the data, survival did not increase with time (Fig. 1C). Survival in wheat treated with 6.0 ppm chlorpyrifos-methyl increased slowly to a maximum of 71.2% at month 10. Quadratic regression fitted the data extremely well (Fig. 1D).

The number of $F_1$ adults collected from the 0, 2, 4, 6, 8 and 10 month bioassays of untreated wheat were 864.0 ± 26.5, 970.2 ± 80.8, 1105.0 ± 75.9, 1443.7 ± 112.0, 1825.0 ± 126.7 and 1438.0 ± 249.7, respectively. Subsequent $F_1$ adults were found in the 8- and 10-month bioassays of wheat treated with 6 ppm chlorpyrifos-methyl (1.0 ± 0.40 and 9.50 ± 2.1, respectively). No $F_1$s were ever found in any of the three deltamethrin treatments or the two combination treatments.

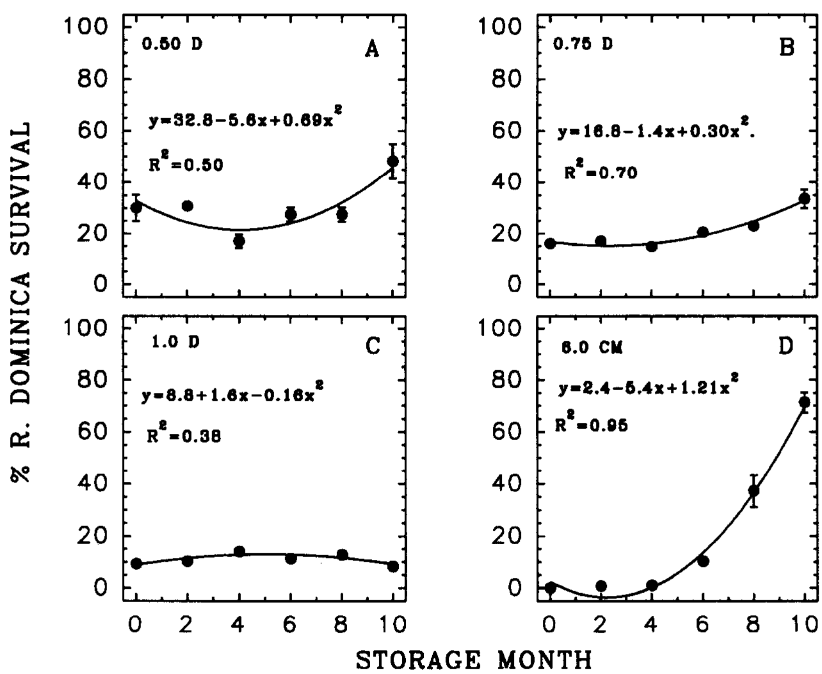


Fig. 1. Mean percentage (±SEM) *R. dominica* survival on wheat treated with 0.5, 0.75 and 1.0 ppm deltamethrin (D) or 6.0 ppm chlorpyrifos-methyl (CM) and stored under ambient conditions for 10 months. Bioassays were made by exposing 100 adults on 320-g wheat samples removed from storage after 0, 2, 4, 6, 8 and 10 months; $y$ = % survival and $x$ = month for regression equations.

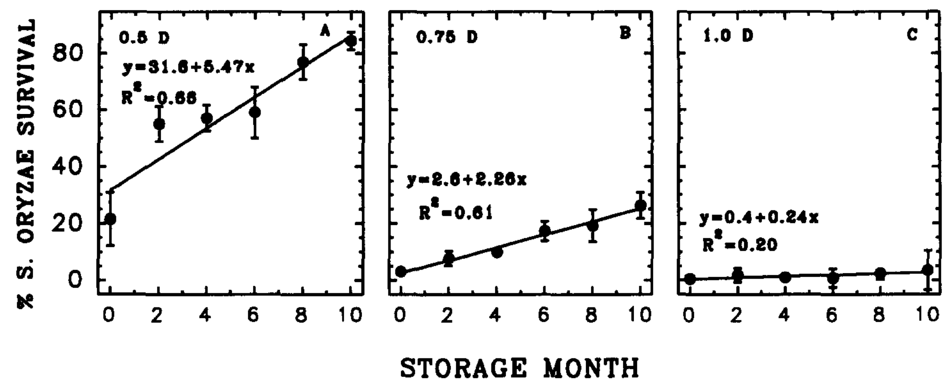


Fig. 2. Mean percentage (±SEM) *S. oryzae* survival on wheat treated with 0.5, 0.75 or 1.0 ppm deltamethrin (D) and stored under ambient conditions for 10 months. Bioassays were made by exposing 100 adults on 320-g wheat samples removed from storage after 0, 2, 4, 6, 8 and 10 months; $y$ = % survival and $x$ = month for regression equations.

Dockage in bioassays at 0, 2, 4, 6, 8 and 10 months in untreated controls was 9.7 ± 0.35, 10.7 ± 0.84, 11.6 ± 0.71, 19.2 ± 0.11, 20.7 ± 2.11, and 22.2 ± 7.5 g, respectively. No dockage was collected in treated wheat after 49 days, with the exception of the dockage collected after bioassays at months 8 and 10 in wheat treated with 6.0 ppm chlorpyrifos-methyl (0.2 ± 0.00 and 0.8 ± 0.03 g, respectively).

*S. oryzae* survival on untreated wheat averaged 95.0 ± 1.6, 93.0 ± 0.7, 95.7 ± 1.3, 96.7 ± 0.8, 94.7 ± 2.4, and 92.3 ± 0.9% at months, 0. 2, 4, 6, 8 and 10, respectively. *S. oryzae* did not survive on wheat treated with either 6 ppm chlorpyrifos-methyl or the two chlorpyrifos-methyl + deltamethrin combinations. Deltamethrin applied at 0.5 ppm did not control *S. oryzae*; survival exceeded 50% after 2 months and increased steadily to 84.5% at 10 months, and this increase was linear with time (Fig. 2A). *S. oryzae* survival on wheat treated with 0.75 ppm deltamethrin ranged from 4.7 to 26.2%, with a slight linear increase with time (Fig. 2B). Maximum *S. oryzae* survival on wheat treated with 1.0 ppm deltamethrin was 3.5 ± 1.5% at 10 months (Fig. 2C).

An average of 116.3 ± 87.0 $F_1$ adults were detected in the 10-month samples for wheat treated with 6.0 ppm chlorpyrifos-methyl, but no other samples from this treatment contained $F_1$ adults. No $F_1$s were found in the combination treatments. Large numbers of *S. oryzae* $F_1$ progeny were produced in the 0.5 ppm deltamethrin treatment (Table 1). The number of $F_1$s in wheat treated with 0.75 ppm deltamethrin increased to a maximum of 157.7 at month 10. Few $F_1$s were produced in wheat treated with 1.0 ppm deltamethrin. Dockage in the 6 ppm chlorpyrifos-methyl treatment at 8 and 10 months was 0.2 ± 0.00 and 0.8 ± 0.03 g, respectively. No dockage was found in the chlorpyrifos-methyl + deltamethrin combinations. The amount of dockage in the 0.5-ppm deltamethrin treatment increased to 4.9 g at month 10 (Table 1). The amount of dockage decreased

Table 1. Number of *S. oryzae* $F_1$ adults (mean ± SEM) and gram weight of dockage (mean ± SEM) after 49 days in 320 g untreated wheat, wheat treated with 0.5, 0.75 and 1.0 ppm deltamethrin, 6.0 ppm chlorpyrifos-methyl[a], 0.5 ppm deltamethrin[b] + 6.0 ppm chlorpyrifos-methyl[b], or 1.0 ppm deltamethrin + 6.0 ppm chlorpyrifos-methyl[b]. The wheat was initially infested with 100 *S. oryzae*, survival was assessed after 5 days and all live and dead *S. oryzae* were removed

| Insecticide treatment | Bioassay month 0 | 2 | 4 | 6 | 8 | 10 |
|---|---|---|---|---|---|---|
| | | | *$F_1$ Adults* | | | |
| Untreated controls | 1543.0 ± 72.6 | 1239.7 ± 144.2 | 1635.5 ± 132.5 | 166.25 ± 99.5 | 1198.0 ± 147.7 | 1498.3 ± 185.2 |
| 0.5 ppm deltamethrin | 222.0 ± 94.0 | 515.0 ± 55.0 | 666.0 ± 131.0 | 630.0 ± 135.0 | 882.0 ± 112.0 | 1145.0 ± 39.0 |
| 0.75 ppm deltamethrin | 4.4 ± 4.2 | 15.5 ± 9.4 | 21.0 ± 6.7 | 49.5 ± 17.3 | 44.0 ± 17.7 | 154.7 ± 28.2 |
| 1.0 ppm deltamethrin | 1.0 ± 1.7 | 2.5 ± 1.3 | 1.5 ± 1.2 | 3.2 ± 3.2 | 2.2 ± 0.8 | 7.0 ± 4.8 |
| | | | *Dockage weight in grams* | | | |
| Untreated controls | 7.1 ± 0.35 | 4.7 ± 0.64 | 5.9 ± 0.52 | 7.6 ± 0.42 | 6.1 ± 0.65 | 16.1 ± 11.5 |
| 0.5 ppm deltamethrin | 0.7 ± 0.23 | 1.5 ± 0.27 | 1.9 ± 0.51 | 2.4 ± 0.73 | 3.5 ± 0.65 | 4.9 ± 0.32 |
| 0.75 ppm deltamethrin | 0.1 ± 0.02 | 0.2 ± 0.06 | 0.2 ± 0.00 | 0.3 ± 0.09 | 0.3 ± 0.09 | 0.6 ± 0.11 |
| 1.0 ppm deltamethrin | 0.1 ± 0.03 | 0.3 ± 0.23 | 0.0 ± 0.00 | 0.0 ± 0.00 | 0.1 ± 0.05 | 0.1 ± 0.03 |

[a]116.3 ± $F_1$ adults collected at month 10 and dockage weight was 0.8 ± 0.003 g. Dockage at 8 months was 0.2 ± 0.00 g; all other values for $F_1$ adults and dockage weight was 0.

[b]No live $F_1$ or dockage in these treatments.

Table 2. Correlation coefficient ($r$)[a] for initial survival of *R. dominica* and *S. oryzae* on all 7 treatments vs $F_1$ adults, survival vs dockage, and $F_1$ adults vs dockage

| | | Bioassay month | | | | | |
|---|---|---|---|---|---|---|---|
| Species | | 0 | 2 | 4 | 6 | 8 | 10 |
| *R. dominica* | Survival vs $F_1$ | 0.93 | 0.92 | 0.96 | 0.93 | 0.86 | 0.65 |
| | Survival vs dockage | 0.94 | 0.92 | 0.96 | 0.94 | 0.85 | 0.62 |
| | $F_1$ vs dockage | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.98 |
| *S. oryzae* | Survival vs $F_1$ | 0.92 | 0.93 | 0.95 | 0.95 | 0.87 | 0.77 |
| | Survival vs dockage | 0.93 | 0.82 | 0.88 | 0.82 | 0.70 | 0.57 |
| | $F_1$ vs dockage | 0.88 | 0.84 | 0.84 | 0.86 | 0.92 | 0.80 |

[a]All $r$ values significant at $P \leqslant 0.01$.

in both the 0.75 and 1.0 ppm deltamethrin treatments. At each bi-monthly bioassay, *R. dominica* and *S. oryzae* survival were positively correlated with subsequent $F_1$s and dockage weight (Table 2). $F_1$s and dockage weight were also positively correlated.

*Corn*

*S. zeamais* survival on untreated corn averaged 94.0 ± 1.2, 93.0 ± 1.3, 96.5 ± 0.5, 95.0 ± 1.3, 94.5 ± 1.5, 92.0 ± 1.2% at months 0, 2, 4, 6, 8 and 10, respectively. No *S. zeamais* survived on the two chlorpyrifos-methyl + deltamethrin treatments. *S. zeamais* survival on corn treated with 0.5 ppm deltamethrin ranged from 3.5 to 23.5%; linear regression was significant with a poor fit (Fig. 3A). Survival in the 0.75 and 1.0-ppm deltamethrin treatments was reduced but the averages fluctuated during the test and there was no significant regression with time in either treatment ($P > 0.05$, Fig. 3B, C). Survival in corn treated with 6.0 ppm chlorpyrifos-methyl was 0, except for 9.0 ± 3.78% survival at month 10. The number of $F_1$ adults collected from the 0, 2, 4, 6, 8 and 10-month bioassays of untreated corn were 207.0 ± 23.4, 132.5 ± 11.6, 107.3 ± 15.1, 173.7 ± 20.0, 203.5 ± 31.2, and 176.7 ± 12.5, respectively.

No subsequent $F_1$ adults were detected in any bioassay samples, except for 13.5 ± 4.52 in 6.0 ppm chlorpyrifos-methyl bioassays from month 10. Dockage in that particular sample was 0.2 ± 0.05 g, and no other sample from any treatment contained more than 0.1 g of dockage. Dockage in the 0, 2, 4, 6, 8 and 10-month bioassays of untreated corn was 2.9 ± 0.40, 2.0 ± 0.07, 1.8 ± 0.23, 3.2 ± 0.30, 3.1 ± 0.47 and 4.2 ± 0.41 g, respectively.

*T. castaneum* survival on untreated corn averaged 99.0 ± 0.4, 99.7 ± 0.2, 99.0 ± 0.4, 99.5 ± 0.3, 98.7 ± 0.5, and 98.7 ± 0.3% at months 0, 2, 4, 6, 8 and 10, respectively. *T. castaneum* survival on corn treated with all 3 rates of deltamethrin was extremely variable during the study, with no significant regression with time in any of these three treatments ($P > 0.05$, Fig. 4A–C). Survival on corn treated with chlorpyrifos-methyl was 0, except for an average of 84.5 ± 3.54% at month 10. However, only 0.5 ± 0.29 $F_1$ adults were subsequently found in this sample.

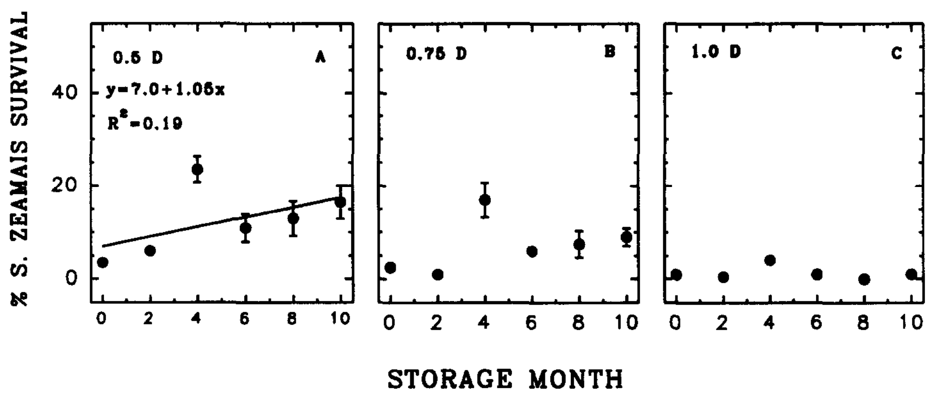


Fig. 3. Mean percentage survival (±SEM) for *S. zeamais* on corn treated with 0.5, 0.75 and 1.0 ppm deltamethrin (D) and stored under ambient conditions for 10 months. Bioassays were made by exposing 100 adults on 320-g corn samples removed from storage after 0, 2, 4, 6, 8 and 10 months; $y$ = survival and $x$ = month of introduction for the regression equations.

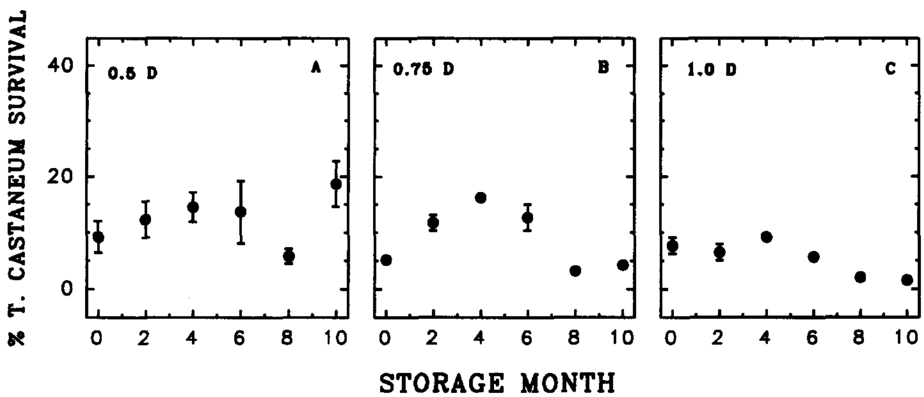


Fig. 4. Mean percentage survival (±SEM) for *T. castaneum* on corn treated with 0.5, 0.75 and 1.0 ppm deltamethrin (D) and stored under ambient conditions for 10 months. Bioassays were made by exposing 100 adults on 320 g corn removed from storage after 0, 2, 4, 6, 8 and 10 months.

The number of $F_1$ adults collected from the 0, 2, 4, 6, 8 and 10 month bioassays of untreated corn was $9.7 \pm 1.6$, $2.7 \pm 0.5$, $5.7 \pm 0.8$, $12.0 \pm 4.7$, $14.0 \pm 1.7$, and $19.0 \pm 4.0$, respectively. The number of $F_1$ larvae collected from these same samples was $527.5 \pm 52.5$, $420.0 \pm 50.5$, $472.5 \pm 12.0$, $515.0 \pm 64.3$, $451.2 \pm 69.2$, and $185.7 \pm 57.2$, respectively. No $F_1$ adults or larvae were produced in any of the treated samples, and dockage never exceeded 0.1 g. Dockage in the 0, 2, 4, 6, 8 and 10 month bioassays of untreated corn was $2.2 \pm 0.13$, $1.6 \pm 0.27$, $2.2 \pm 0.16$, $2.9 \pm 0.27$, $2.6 \pm 0.19$, and $2.5 \pm 0.47$ g, respectively.

At each bi-monthly bioassay, *S. zeamais* survival, subsequent $F_1$s, and dockage weight were all positively correlated (Table 3). All four variables for *T. castaneum*, survival, $F_1$ larvae, and dockage weight were also positively correlated at each bioassay (Table 3).

## DISCUSSION

Deltamethrin residues from applications of either 0.5, 0.75 or 1.0 ppm on wheat controlled *R. dominica* for at least 10 months, but an application rate of at least 1.0 ppm was necessary to give equivalent control of *S. oryzae*. Previous studies have also noted that other pyrethroids did not exhibit the same degree of effectiveness toward *R. dominica* and *Sitophilus* spp. Halliday *et al.* (1992) showed that *R. dominica* was slightly more susceptible than *S. oryzae* to unsynergised and synergised tralomethrin residues on wheat. Similarly, Bengston *et al.* (1987) reported that several *S. oryzae* strains were less susceptible than *R. dominica* strains to synergised cyfluthrin and cypermethrin. Arthur *et al.* (1992) found that unsynergised resmethrin and unsynergised bioresmethrin applied at 2 and 5 ppm controlled *R. dominica* on wheat, but neither rate controlled *S. oryzae*. Nicolas *et al.* (1991) indicated deltamethrin application of 0.125 and 0.375 ppm + 2.5 ppm piperonyl butoxide on wheat killed all *R. dominica* after the wheat was stored for 6 months, but comparative mortality of *Sitophilus granarius* (L.) and *S. oryzae* was 36 and 12%,

Table 3. Correlation coefficient ($r$)[a] for initial survival of *S. zeamais* on all 7 treatments vs $F_1$ adults, survival vs dockage, and $F_1$ adults vs dockage; survival on *T. castaneum* vs $F_1$ adults, survival vs $F_1$ larvae, survival vs dockage, $F_1$ adults vs dockage, and $F_1$ larvae vs dockage

| Species | | Bioassay month 0 | 2 | 4 | 6 | 8 | 10 |
|---|---|---|---|---|---|---|---|
| *S. zeamais* | Survival vs $F_1$ | 0.98 | 0.99 | 0.93 | 0.97 | 0.95 | 0.97 |
| | Survival vs dockage | 0.97 | 0.99 | 0.93 | 0.97 | 0.96 | 0.97 |
| | $F_1$ vs dockage | 0.99 | 0.99 | 0.98 | 0.99 | 0.99 | 0.99 |
| *T. castaneum* | Survival vs $F_1$ adults | 0.95 | 0.94 | 0.94 | 0.95 | 0.96 | 0.60 |
| | Survival vs $F_1$ larvae | 0.97 | 0.96 | 0.98 | 0.79 | 0.97 | 0.65 |
| | Survival vs dockage | 0.98 | 0.94 | 0.97 | 0.96 | 0.99 | 0.63 |
| | $F_1$ adults vs dockage | 0.97 | 0.97 | 0.96 | 0.89 | 0.97 | 0.99 |
| | $F_1$ larvae vs dockage | 0.98 | 0.99 | 0.99 | 0.99 | 0.99 | 0.96 |

[a]All $r$ values significant at $P \leqslant 0.01$.

respectively. These results emphasize the necessity of conducting insecticide evaluations on both of these genera and including some of the additional species (such as *Cryptolestes*) that can infest stored wheat and stored corn.

The toxicity data for unsynergised deltamethrin obtained in this study conflict with results from Samson and Parker (1989). In their study, 4 ppm was the lowest effective application rate that would control *S. oryzae* on corn for 24 weeks, and the estimated application rate for control after 32 weeks exceeded 6 ppm. However, in my study 1 ppm deltamethrin protected wheat from *S. oryzae* and corn from *S. zeamais* for 10 months (approx. 40 weeks). One possible explanation for the discrepancy was that Samson and Parker (1989) conducted bioassays with field strains, and it is possible that deltamethrin resistance or pyrethroid cross-resistance was developing in some of these strains (Samson and Parker, 1990). Cross-resistance between pyrethroids can be induced under laboratory selection pressure (Heather, 1986). Bioassays in my study were conducted with pesticide-susceptible laboratory strains, which may have been more susceptible than field strains to deltamethrin.

Residual toxicity data for *Tribolium castaneum* indicate that this species would also be controlled by low application rates of deltamethrin. Even though variable survival was measured throughout the test during the initial bioassays, no $F_1$ progeny were detected in any deltamethrin treatment. Data from Samson and Parker (1990) also indicate that *T. castaneum* was less susceptible than *R. dominica* and more susceptible than *S. oryzae* to deltamethrin. Arthur (1992) obtained similar results with the pyrethroids resmethrin and bioresmethrin.

Although no pyrethroids are currently registered in the United States as grain protectants, they may receive more attention in the future because unlike organophosphates, residue degradation rates do not increase with increases in commodity temperature and moisture content. Application rates for pyrethroid protectants would probably be lower than current rates for comparable organophosphates.

In conclusion, deltamethrin has excellent potential for use as a protectant of either stored corn or stored wheat. An application rate of 1 ppm may be sufficient to control insect species of these commodities. However, further research is necessary regarding deltamethrin persistence and biological efficacy in the differing climatic regimes of the United States. In some areas it may be necessary to apply deltamethrin in combination with chlorpyrifos-methyl to control the various insect pest species.

*Acknowledgements*—I thank J. E. O'Bryan and G. W. Murray for their excellent technical assistance.

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